Chapter 8

Milling Operations

Stupidity is the basic building block of the universe.
—Frank Zappa

Introduction

Unlike lathes, which have been known for thousands of years, milling machines are less than two hundred years old. Because they require much more power than hand-driven lathes, their introduction had to wait for the invention of industrial water and steam power. Also, all their mechanical components had to first be made available, such as accurately fitted slides, large castings to resist cutting forces, calibrated leadscrews, and hardened steel cutting tools.

Eli Whitney is credited with inventing the first milling machine about 1818, but the knee-and-column support arrangement of the *universal* milling machine of Joseph A. Brown (later of Brown and Sharpe) dates from 1862 and marks an important step in the machine's development. During the last half of the nineteenth Century, milling machines gradually replaced shapers and planers which have lathe-type, single-point tool bits that move over the work in a straight line and scrape off metal one stroke at a time. Milling machines, with their continuous cutting action, not only remove metal faster than shapers and planers, they perform additional operations like cutting helices for gears and twist drills. Today, milling machines greatly outnumber shaping and planing machines. Americans in New England and later the mid-west continuously added features leading to the modern milling machine.

Another important development came in the 1930s when Rudolph Bannow and Magnus Wahlstrom brought out the Bridgeport-style vertical milling machine. This design offers versatility and economy in place of the higher metal removal rates of traditional horizontal milling machines. Because of this versatility, there are more Bridgeport-style mills in existence today than any other milling machine design. Horizontal mills are now usually reserved for production applications where high metal removal rates on identical parts are needed, not prototyping and short runs. Bridgeport-style machines are also

called *knee-and-column machines* and *turret mills*. The key features of these machines are a:

- Knee-and-column support for the milling table, which provides vertical motion of the work with respect to the tool.
- Saddle which supports the table to provide in-and-out motion from the vertical column.
- One-piece tool head which holds the motor, drive pulleys, and spindle.
- Sliding *overarms* or *rams* were eventually added to allow the tool head to be moved in or out with respect to the vertical column. Some machines have provisions for the tool head to be tilted side to side or back to front.

The Bridgeport-style machine offers many advantages over the older horizontal milling machine design:

- The biggest advantage is the quill's ability to advance and retract the cutter easily *without* cranking to raise and lower the milling table. This speeds production and reduces operator fatigue. The retractable quill lets the operator quickly withdraw the tool to clear chips from a hole or check its progress. Tactile feedback through the quill feed handle or handwheel also tells the machinist how the tool is cutting and lets him optimize feed with less danger of tool breakage. Vertical table movement is still available for high-accuracy depth adjustment or when more force on the tool is required.
- The second largest advantage is the Bridgeport-style machine's ability to make angle cuts. With the horizontal milling machine, either the milling cutter is made on an angle, or the work must be positioned at an angle to the spindle axis. With the Bridgeport-style machine the operator merely needs to tilt the spindle to make an angle cut. Of course, the Bridgeport can also use an angled cutter or mount the work on an angle.
- Vertical milling machines must use smaller cutting tools than horizontal mills because they have less rigid, less massive castings, and lower horsepower motors. Still, they can accomplish the same end results as the horizontal mill, just more slowly.
- Vertical milling machines are less complex than horizontal machines because the one-piece tool head eliminates the need for complicated gearing *inside* the vertical column.
- Bridgeport-type milling machines usually have 1 to 5-horsepower motors, and smaller castings than most horizontal mills. Because of this they generally cost less.
- Knee-and-column mills offer versatility and economy in place of the high metal removal rates of traditional horizontal milling machines.

There are between 15 and 36 milling machine designs or styles, depending on who is counting, but the focus of this study is the Bridgeport-style vertical knee mill because they are most often used in shops doing prototyping and R&D work. They outnumber all other designs combined. This design has so much to offer that it has been copied in every industrialized country. At one time there were no less than thirteen separate Spanish companies building Bridgeport-style mills. A working knowledge of a Bridgeport-style vertical milling machine also provides a good start for operating any other style milling machine.

Lathes and mills are complementary machines. While lathes rotate the workpiece and produce a cylindrical cut, milling machines move work into a rotating cutter and make a straight line cut. Lathes and mills are both capable of boring large-diameter holes, but mills are better at placing holes anywhere on the surface of the work. Although one can sometimes make do with just a lathe or mill, a well-equipped shop must have both machines.

The lathe cutting tool is in continuous contact with the work and so makes a continuous cut. Milling machines are just the opposite. They use multi-tooth cutting tools and their cutting action is intermittent as each tooth takes a bite. Metal is removed in small individual chips. Unlike lathe cutting tools, end mills, the most common cutting tool for Bridgeport-style mills, cannot be sharpened freehand because they must be perfectly symmetrical. Sharpening them requires special fixtures and shaped grinding wheels. Smaller shops send their cutters out for sharpening.

Adding a digital readout (DRO) is a great convenience to any milling machine. It reduces the need to repeatedly stop the mill to make measurements and lowers the chance of errors. When reset to zero, the DRO displays the exact displacement from a reference point on the workpiece making it possible for the operator to work directly with the dimensions on his working drawing.

For production applications, there are large, expensive milling machines with three or more axes under computer control. Some machines perform all operations including automatic tool changing. However, today there is an intermediate step between a manual mill and a fully automated one. Adding a computer, digital readouts, and actuators to the X- and Y-axes of a Bridgeport-style mill does this. Not only can this enhanced machine tirelessly perform all its existing repetitive functions, it also has added new capabilities. Now the mill can engrave (drive the tool to cut numbers and letters in various sizes and fonts), cut radii and angles without a rotary table, make islands, pockets, and cut ellipses, and frames. Entering the position, diameter and number of holes, automates cutting a bolt-hole pattern; the system does the

math. The computer can automatically compensate for the reduced diameter of resharpened milling cutters, saving time and money. The system can be manually programmed through its control panel, use stored programs, “learn” new tasks by memorizing a series of manual operations as the operator makes the first part, or accept files from CAD programs.

In this chapter we will study two mills, the Sherline miniature milling machine and the classic, full-sized Bridgeport® by Hardinge®. First, we will look at each machine, then examine its major components and study each of its adjustments and controls. Next, we will look at milling machine cutting tools and accessories, and learn its step-by-step operation. Finally, we will review milling machine safety issues.